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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Appln. No.	:	10/006,535 Confirmation No.: 1081
Applicant	:	FEDERICO CARNIEL et al.
Filed	:	December 5, 2001
TC/A.U.	:	3663
Examiner	:	DEANDRA HUGHES
Docket No.	:	CISCP735
Customer No.	:	26541
Title	:	GAIN FLATTENED BI-DIRECTIONALLY PUMPED RAMAN AMPLIFIER FOR WDM TRANSMISSION SYSTEMS

Commissioner for Patents
P.O. Box 1450
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DECLARATION OF ADA BRAVERMAN UNDER RULE 132

I, Ada Liva Braverman, an inventor of the above-identified patent application do declare as follows:

1. As will be explained, the invention of this patent application provides surprising results to a Raman amplification system by combining the use of N pumps in one pumping direction and N+1 pumps in the other pumping direction where the pump wavelengths alternate between directions.

2. The design of a Raman amplification system involves a complex set of tradeoffs. The Raman amplifier must provide sufficient gain to overcome losses along the span. Generally, the more gain that can be achieved, the greater the distance that can be achieved between optical amplification sites, directly affecting cost of the link. This gain should be achieved over a large bandwidth. The bandwidth of the amplifiers along a link determine how many channels can be carried, directly affecting link revenue.

3. The flatness of gain across the bandwidth is also a highly important figure of merit for Raman amplifiers. To satisfy receiver dynamic range requirements, it is necessary to have a flat gain response across the bandwidth. Flatness can be achieved by the use of gain flattening filters but these have an associated insertion loss that compromises the overall gain.

4. Achieving all of these objectives simultaneously is an enormous challenge. The designer can shift pump wavelengths and adjust pump powers to identify an optimal solution. However, improvements on one front often mean setbacks on another front. Reductions in gain variation across the band may be achieved only at the expense of overall gain. If pump power is increased arbitrarily in an effort to increase gain, there are undesired consequences such as nonlinear effects of gain saturation and four-wave-mixing between signal energy and pump energy.

5. Referring now to the table on page 1 of the Exhibit, simulation results are presented for five different configurations of pump wavelength and pump power. As in the example given at the bottom of page 12 of the present application, a gain of 23 dB is desired to compensate for the loss of a fiber span and multiplexers. The configuration of column 1 is in accordance with the present invention and employs two counter-propagating pump wavelengths and three co-propagating pump wavelengths while the configurations of columns 2-5 use two pump wavelengths of each type. Gain and gain deviation versus wavelength are plotted in Figs. 1-10 of the Exhibit.

6. It is apparent that configuration 1 achieves the desired 23.2 dB simultaneously with 1.2 dB of gain deviation using two co-propagating and three counter-propagating pumps. Configuration 2 represents an optimization of pump powers at the same four wavelengths to achieve the same gain flatness. As can be seen the 1.2 dB gain flatness can be achieved *but only at the expense of a 6.1 dB loss of gain.* This is a highly indicative point of comparison between embodiments of the present invention and the prior art. The 6.1 dB difference in average gain is a very large disparity. In the context of a real-world optical communication system, this would correspond to a loss of hundreds of kilometers, e.g., 1470 km instead of 2000 km, of available span length and a great increase in cost.

7. The remaining columns show configurations optimized to recover the lost gain by varying pump wavelengths and powers. Configuration 3 allows for optimization of pump wavelengths at the expense of shifting of the amplification window away from its target range.

Only half the lost gain is recovered but the gain deviation is doubled compared to what was achieved in configuration 1.

8. Configurations 4 and 5 increase the pump powers of the configuration of column 3 to recover the remaining lost gain. Configuration 5 exhibits 2.0 dB of gain deviation. There is however, a limit to the use of pump power increases to increase gain since undesired non-linear effects such as saturation and four-wave-mixing begin to appear.

9. The combination of gain and gain flatness provided by embodiments of the present invention represents a surprising result. The multiple objectives of gain, gain flatness, and bandwidth are achieved by relying on the features of the claimed invention including the use of N pumps in one pumping direction and N+1 pumps in the other pumping direction where the pump wavelengths alternate between directions.

The undersigned declarant declares further that all statements made herein of their own knowledge are true and all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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EXHIBIT

Simulation Results

Configuration number	1		2		3		4		5	
Pump configuration	2+3		2+2		2+2		2+2		2+2	
Total gain dev.	1.2		1.2		2.4		2.4		2.0	
Min wavelength (nm)	1572		1572		1579.6		1579.6		1578.2	
Max wavelength (nm)	1617		1617		1624.6		1624.6		1623.2	
Bandwidth (nm)	45		45		45		45		45	
Average Gain (dB)	23.2		17.1		20.3		23.3		23	
Pump wavelength (nm) and power (mW)	1455(ctp)	120	1455(ctp)	-	-	-	-	-	-	-
	1472(ctp)	145	1472(ctp)	100	1470	145	1470	220	1470	230
	1509(ctp)	160	1509(ctp)	100	1513	160	1513	205	1513	195
	1463(cop)	215	1463(cop)	200	1459	215	1459	225	1459	235
	1499(cop)	225	1499(cop)	200	1501	225	1501	215	1501	205

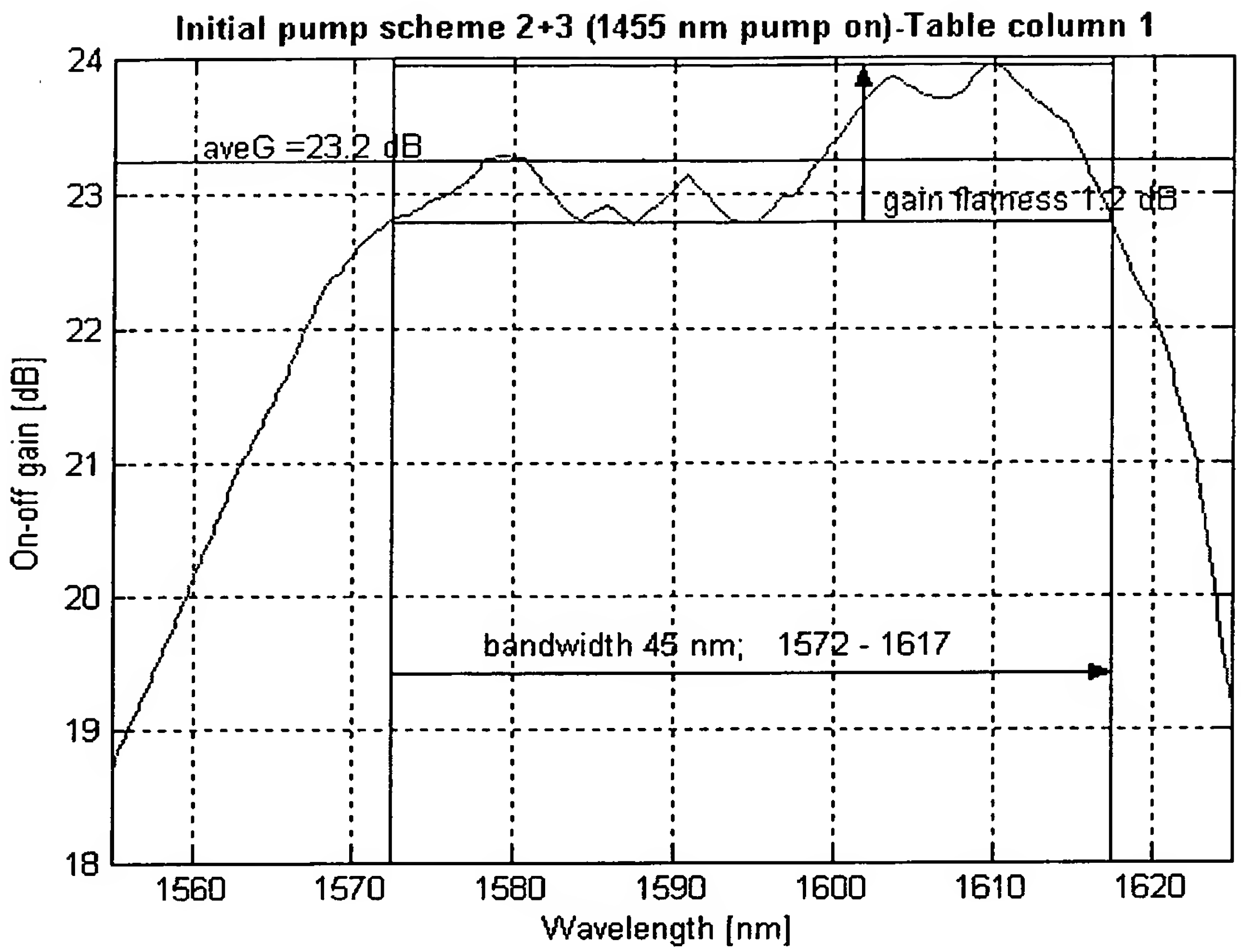

Fig. 1. On-off gain corresponding to the 2+3 pump scheme (column 1)

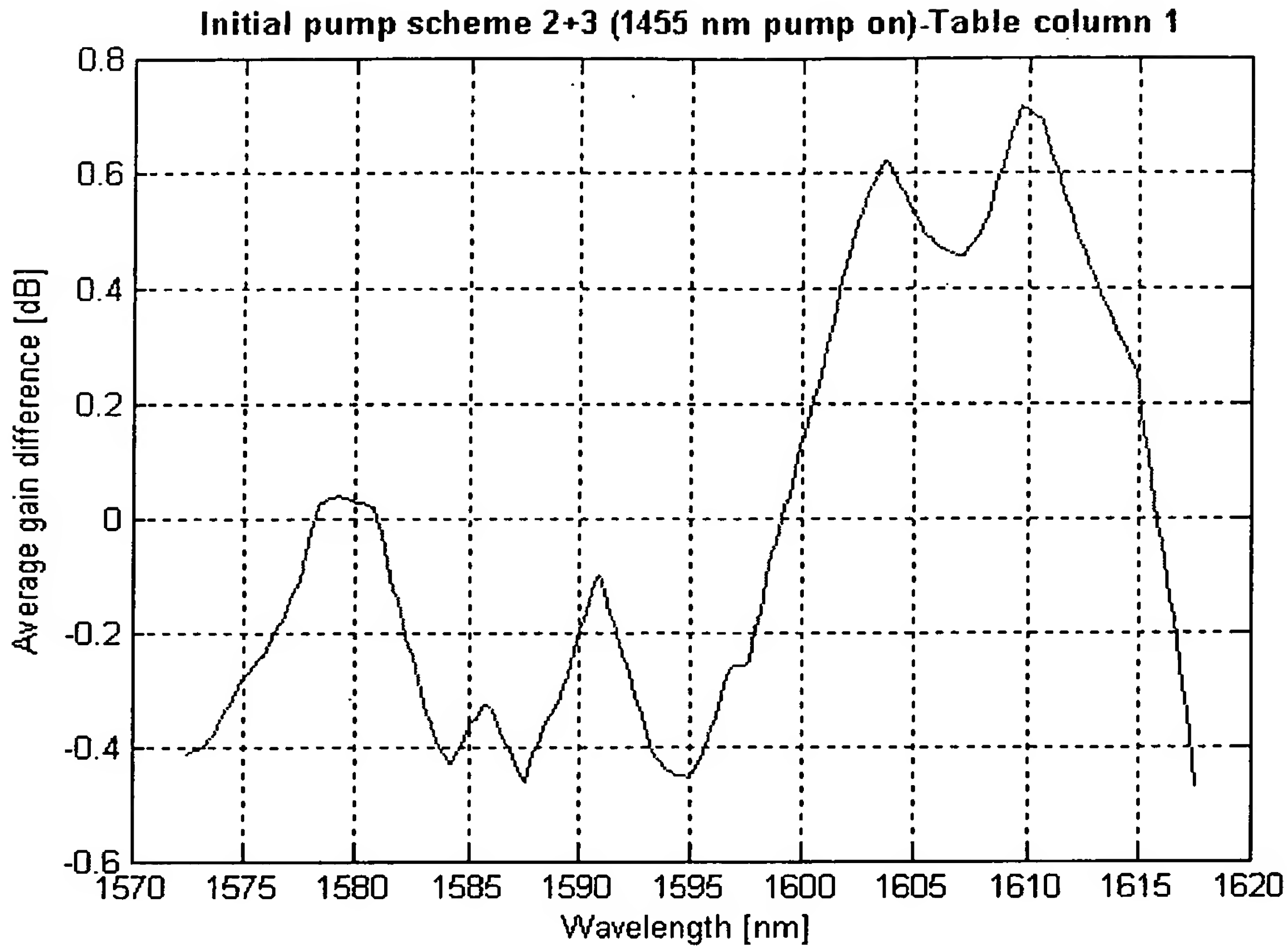

Fig. 2. Average gain deviation corresponding to the 2+3 pump scheme (column 1)

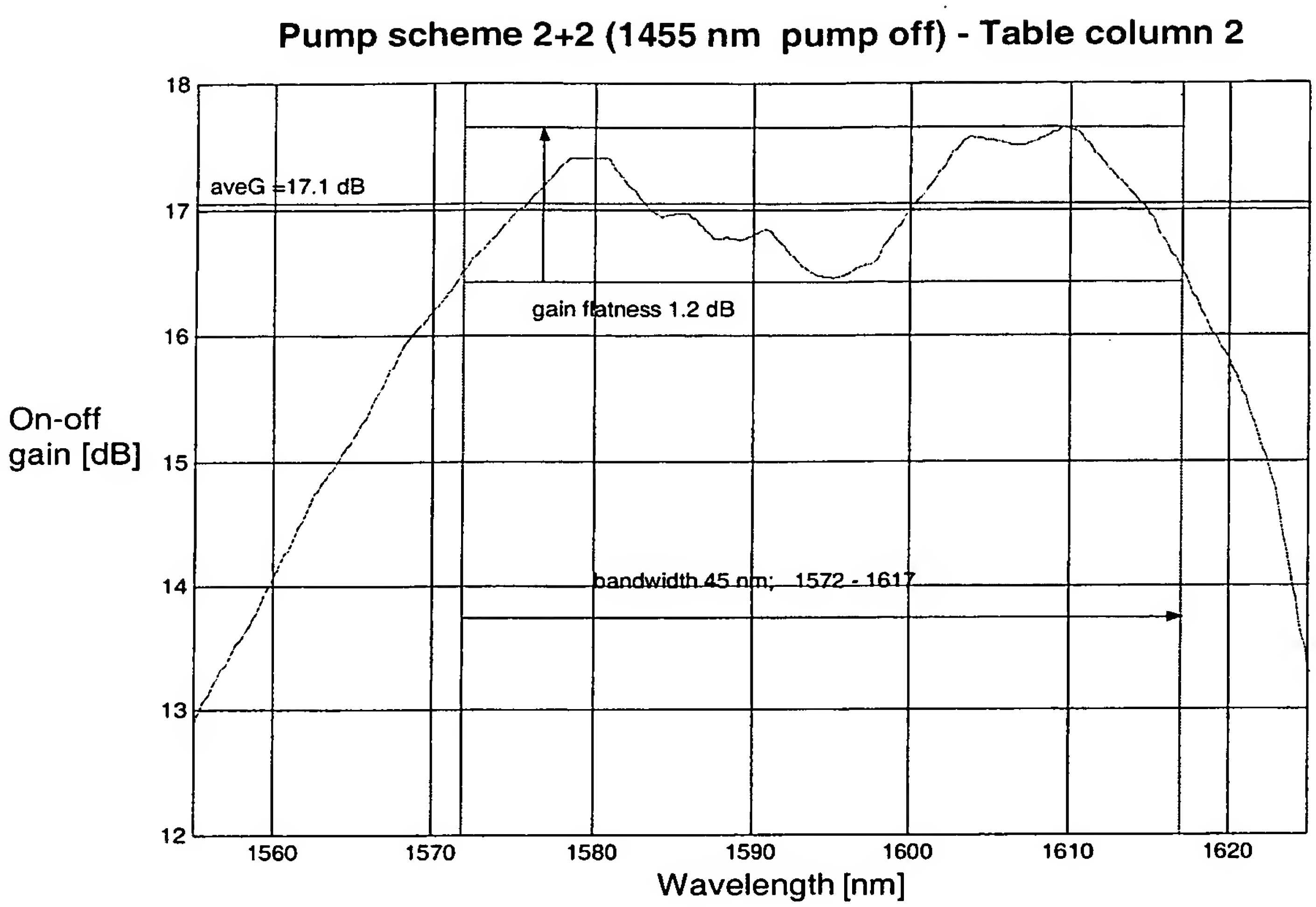

Fig. 3. On-off gain corresponding to the 2+2 pump scheme (column 2)

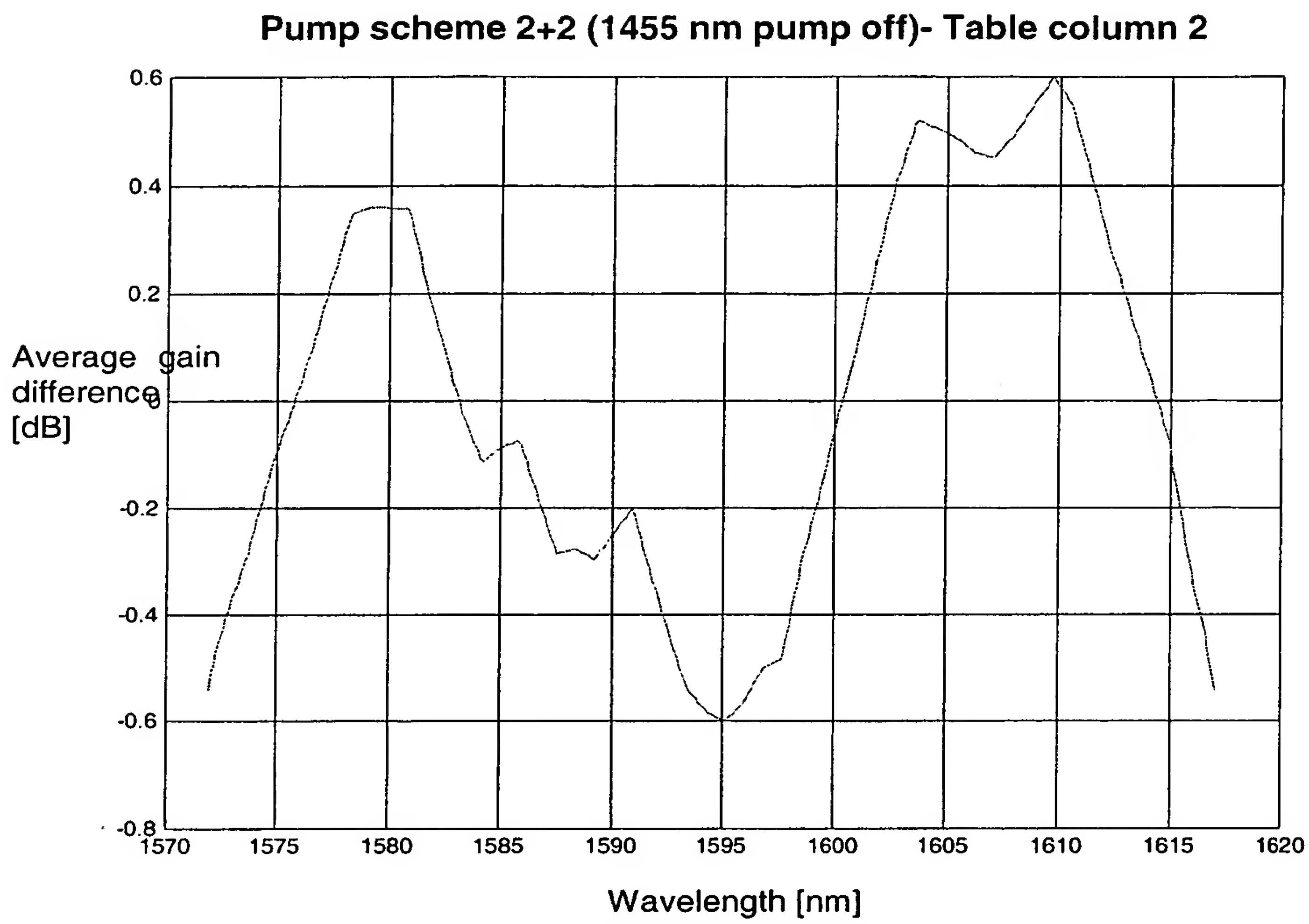

Fig. 4. Average gain deviation corresponding to the 2+2 pump scheme (column 2)

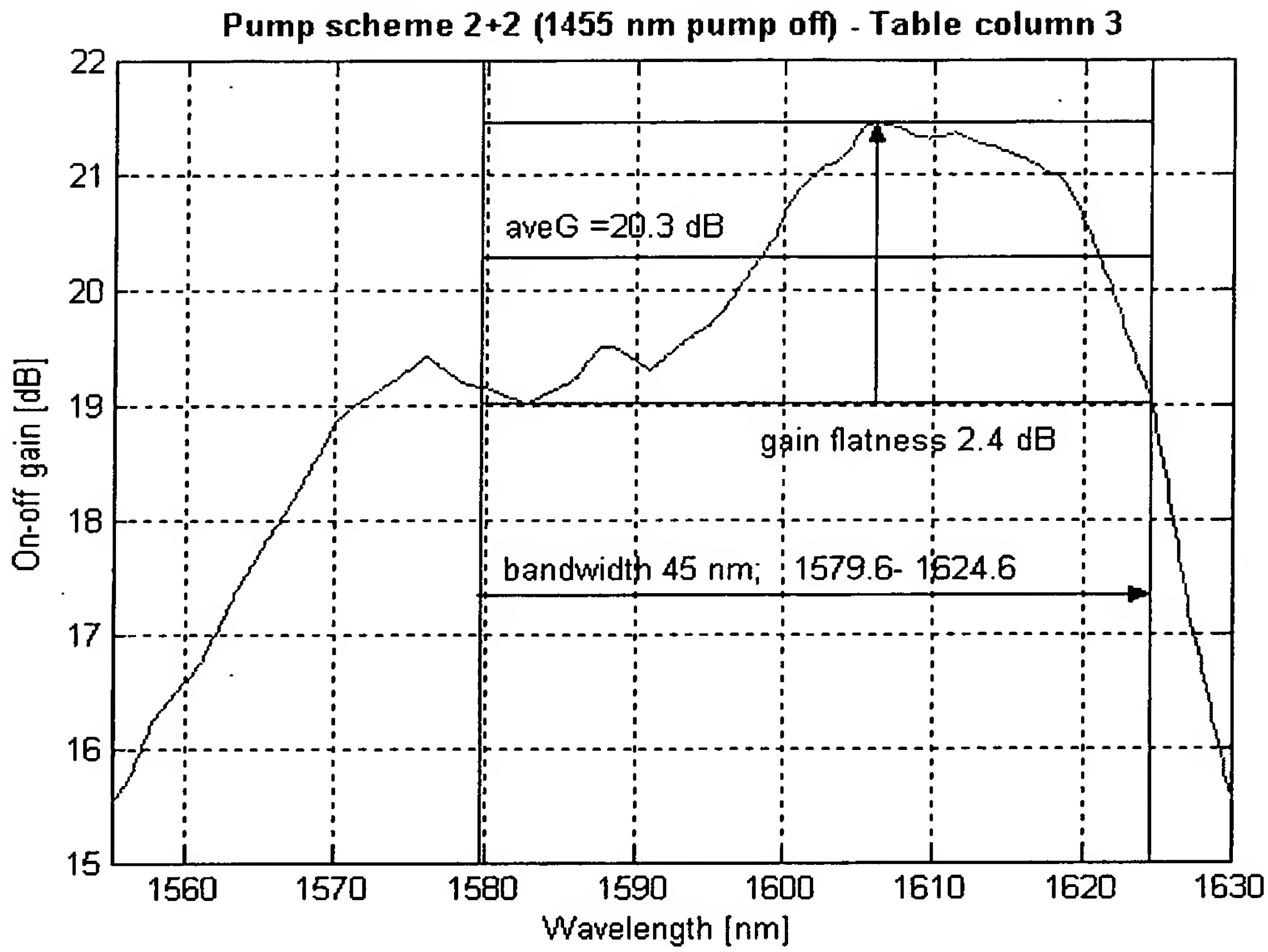

Fig. 5. On-off gain corresponding to the 2+2 pump scheme (column 3)

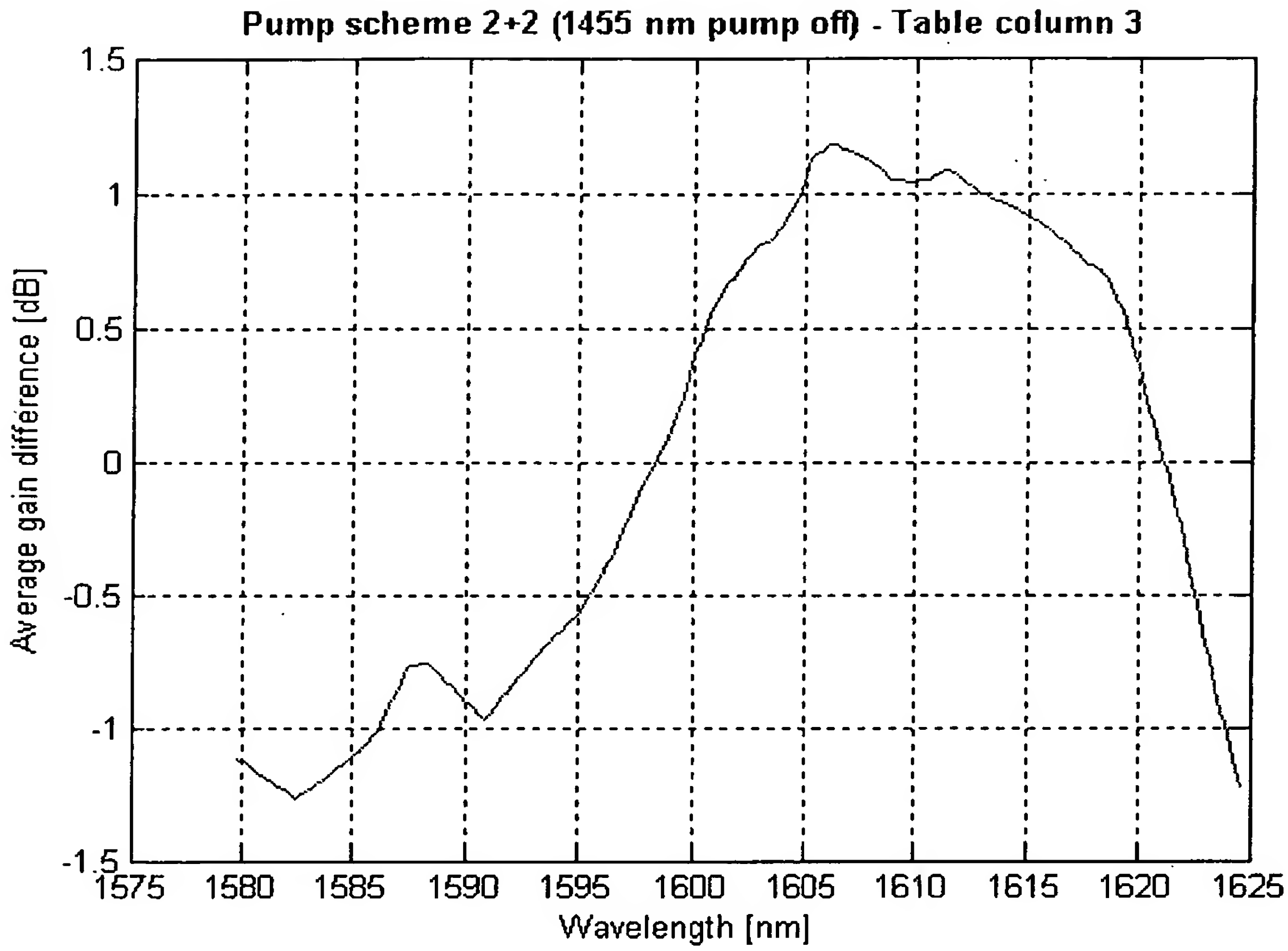

Fig. 6. Average gain deviation corresponding to the 2+2 pump scheme (column 3)

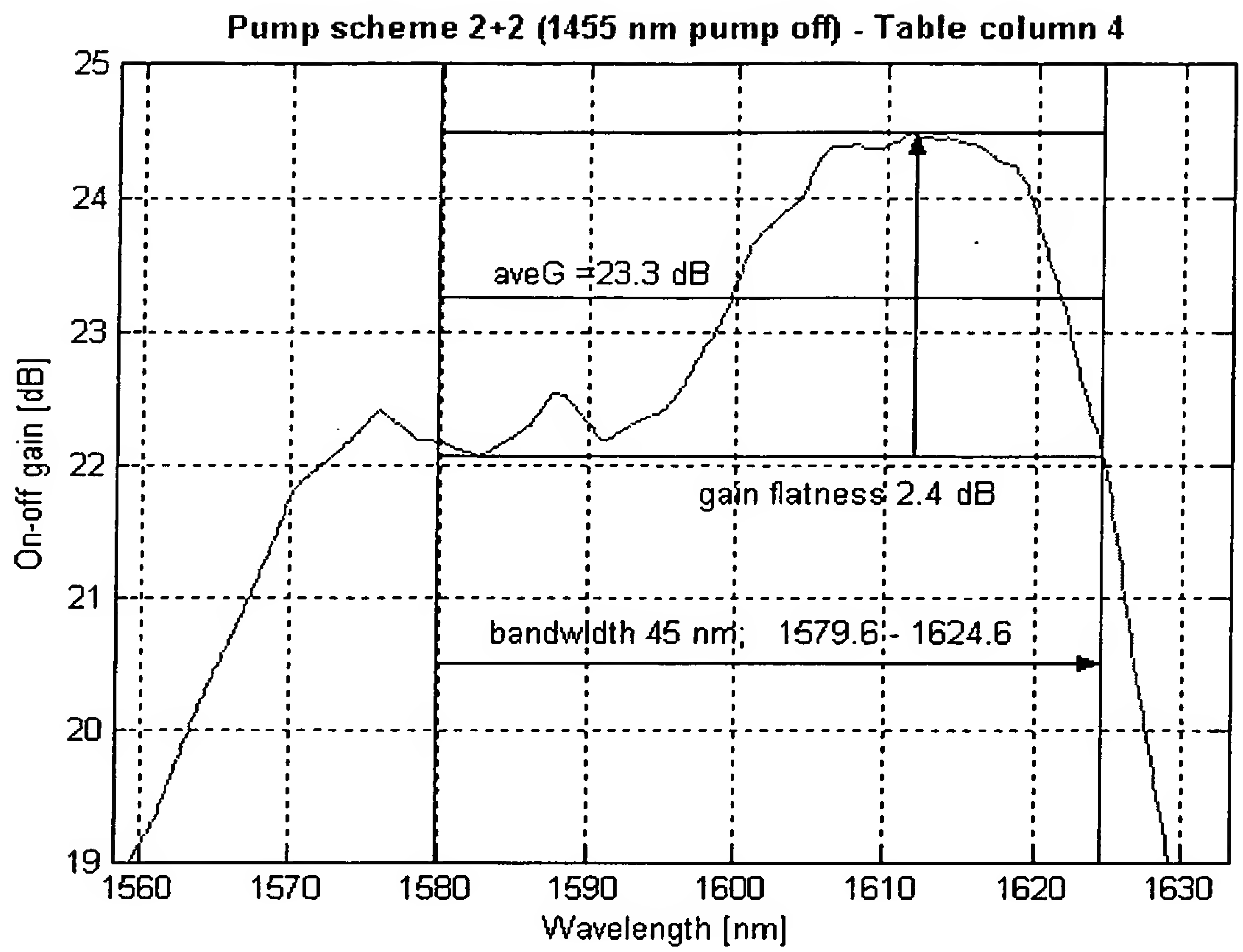

Fig.7. On-off gain corresponding to the 2+2 pump scheme (column 4)

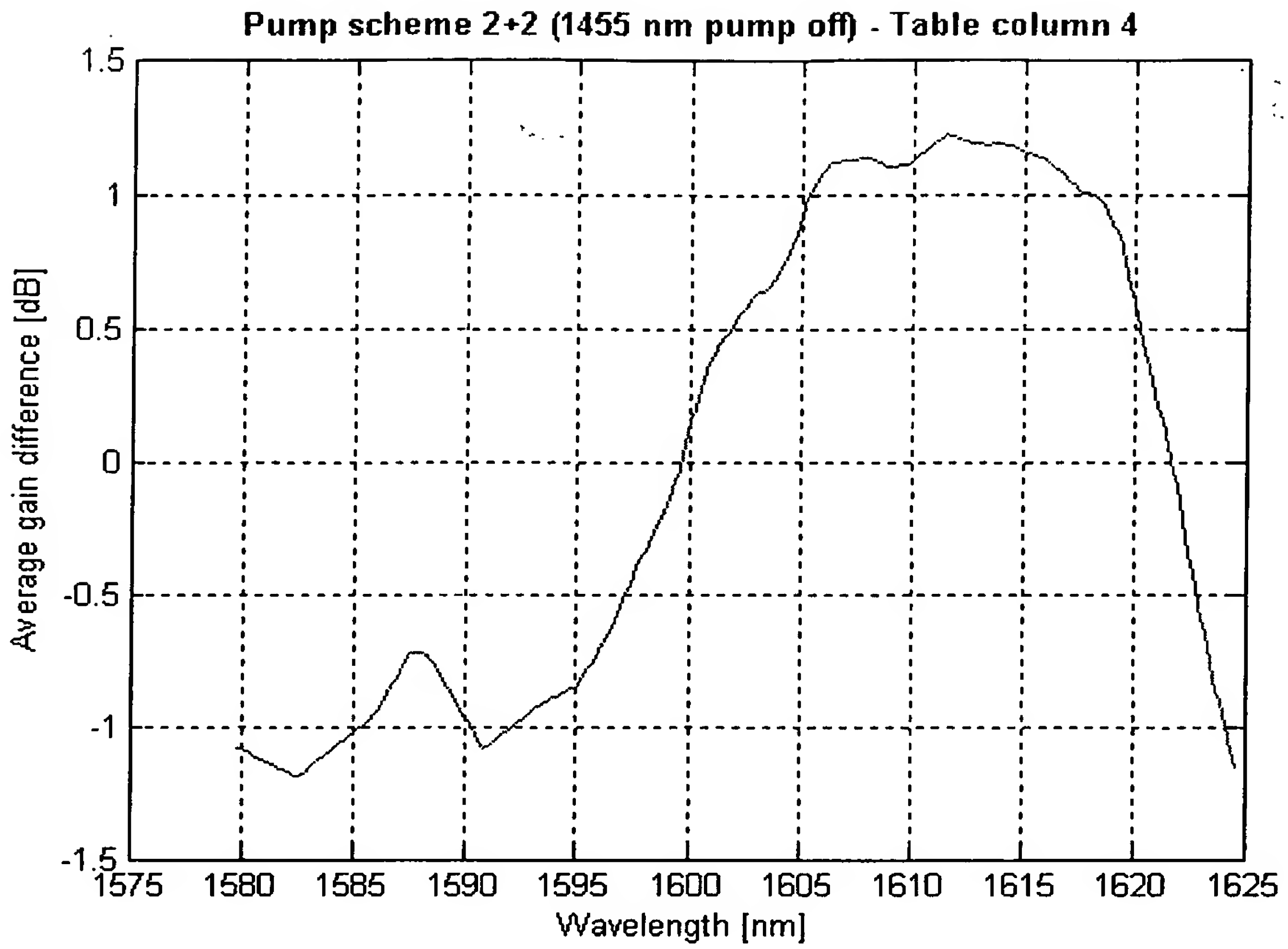

Fig. 8. Average gain deviation corresponding to the 2+2 pump scheme (column 4)

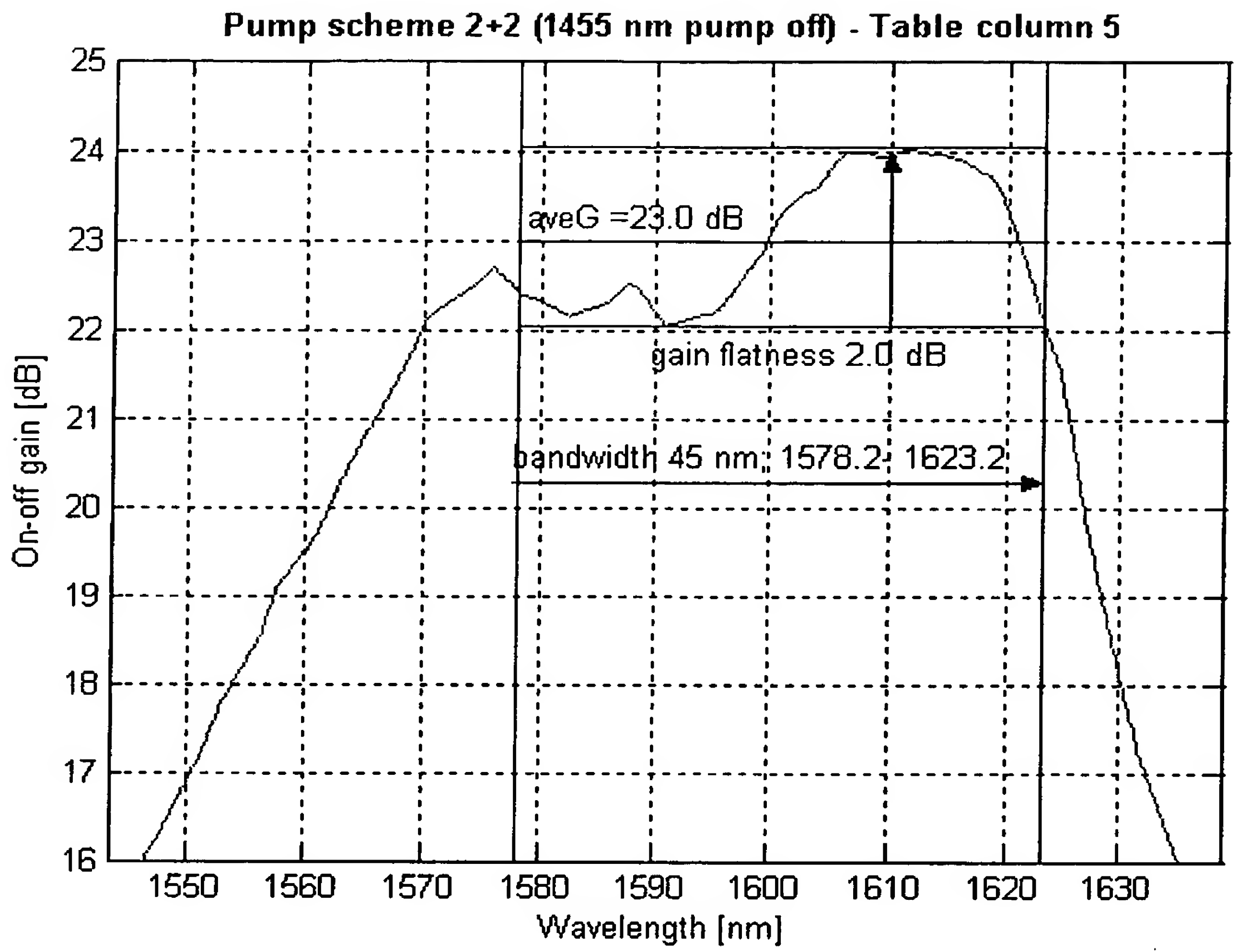

Fig.9. On-off gain corresponding to the 2+2 pump scheme (column 5)

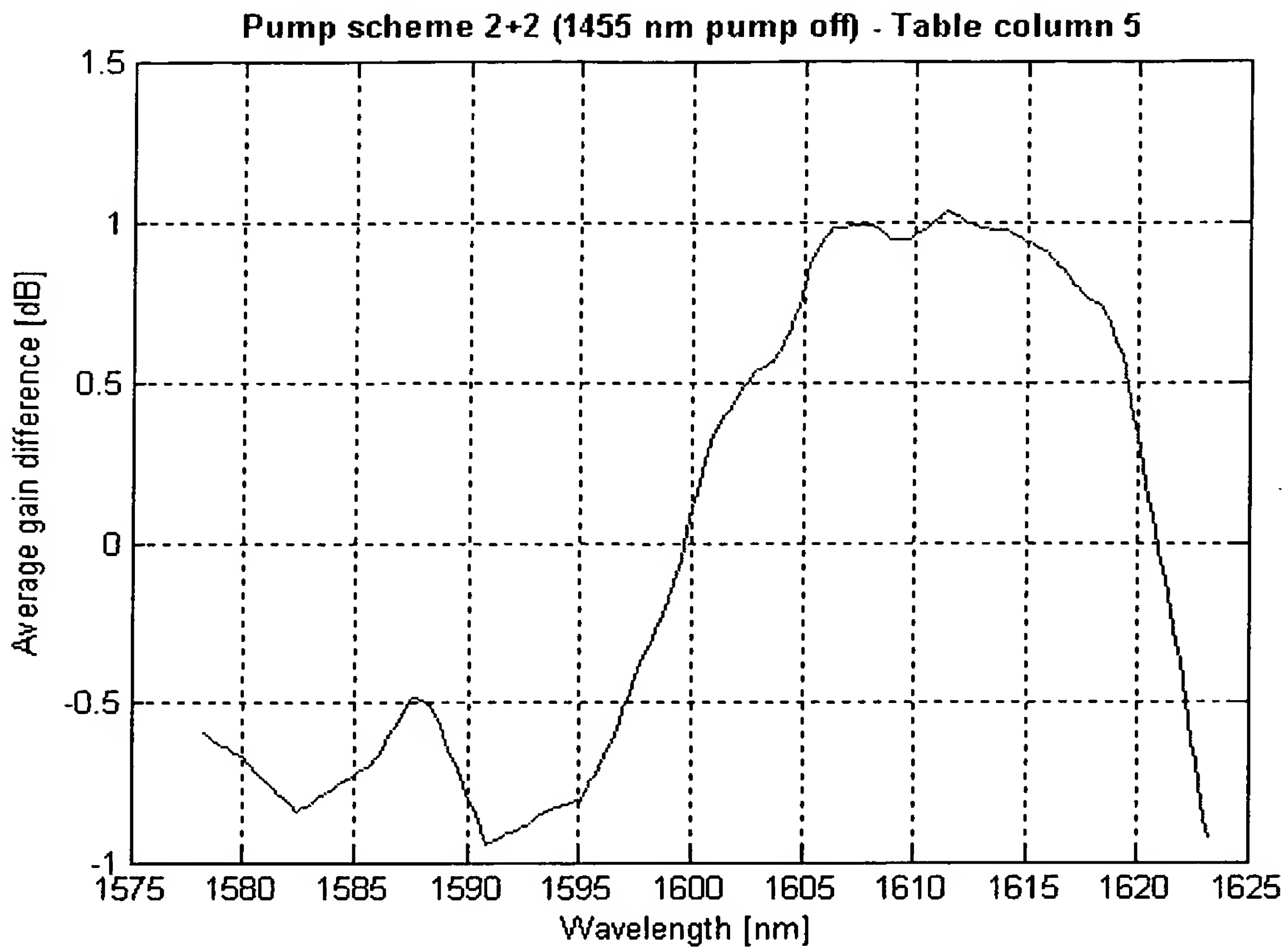

Fig. 10. Average gain deviation corresponding to the 2+2 pump scheme (column 5)